

## Flax-cotton fiber blends: Miniature spinning, gin processing, and dust potential

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### Abstract

Development of a flax (*Linum usitatissimum* L.) industry in North America is desired to supply a domestic source of clean, consistent quality textile fiber for blending with cotton. The objective of this work was to evaluate portions of traditional cotton gin equipment (extractor feeder and lint cleaner) and the “50-g cotton-spinning test (CST)” for flax. Dust was collected on an area sampler in an isolated card room to evaluate dust potential during textile pilot plant processing. Fibers retted by diverse means were cleaned on two separate portions of Continental Eagle’s pilot plant cotton gin stand, the Super 96 Feeder and the 24D lint cleaner. Fibers separated and removed from flax stalks by these gin sections were compared against the standard ‘unified line’ processing technique of the USDA Flax Pilot Plant. Test yarns were then made in a CST with cotton and flax blends to provide an indirect measurement of fiber properties that can be related to the retting and gin cleaning processes. The yarns were tested for strength and evenness. Flax fibers that displayed the most favorable properties in the CST were then spun in 23 kg lots in the pilot plant at the following cotton/flax blend ratios: 100/0, 75/25, 50/50, 25/75, and 20/80. With modifications, it appears that portions of a cotton gin stand are able to process adequately small samples of properly retted flax stalks. The CST with minor adjustments provides useful data for ranking and further large-scale flax processing. As expected, it appears that flax fiber can be successfully cleaned on a cotton processing line and that increasing the amount of flax generates additional dust.

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### 1. Introduction

The plant fiber crops cotton (*Gossypium barbadense* L. or *Gossypium hirsutum* L.) and flax (*Linum usitatissimum* L.) have a long history of being utilized in clothing

by the textile apparel industry due to their comfort level. Cellulose is a major component in these fibers and ranges from 95% in cotton to about 71% in flax (Lewin and Pearce, 1998). While these two natural fibers are similar, the properties of the plant as well as the mandatory processing to obtain fibers vary greatly.

Flax stalks contain approximately 30% fiber and 70% trash both of which have been contaminated by bacterial endotoxins, similar to cotton. A cotton gin cleans cotton fibers and extracts trash (8–36% trash depending upon

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harvest technique) to make textile-grade fibers (Mayfield et al., 1986). The purpose for cotton is similar, but different in design and methodology for processing flax. The “50-g spinning test (CST)” developed for cotton provides a method to test small amounts of fibers and may be applicable to flax to help identify superior flax fibers for a modern flax industry, the utility of flax ginning, and the levels of dust generated in textile processing.

The Cotton Quality Research Station (CQRS), USDA, ARS in Clemson, SC performs cotton fiber and yarn laboratory tests as well as pilot plant studies and the CST, commonly called miniature spinning. Yarn strength and evenness results from such tests have provided an indication of the potential spinning qualities of experimental cotton varieties (Landstreet et al., 1959, 1962; Ewald, 1975; Ramey et al., 1977). Identification of cottons with specific processing properties often leads to larger scale pilot plant processing. The CST was designed to produce yarn from a very small sample of cotton, thus reducing time and cost (Landstreet et al., 1959, 1962; Ewald, 1975).

The Agricultural Research Service of USDA has the responsibility to develop and expand the use of sustainable, environmentally friendly biobased products, such as natural fibers, for a variety of industrial applications. A USDA Flax Pilot Plant (Flax-PP), with a version of a commercial flax cleaning system, has been established at, Clemson, South Carolina (Foulk et al., 2004). The Flax-PP is designed according to the commercial ‘unified line’ (Czech Flax Machinery, Humpolec, Czech Republic). This Flax-PP will provide a better understanding of fiber quality parameters, fiber standards, processing costs, and possibly eliminate uncertainties of raw material supply.

For research purposes, this pilot plant consists of four individual modules with maximum flexibility that are the primary components of the commercial line. Each fiber-processing module can be individually controlled using variable speed drives to study the effect of equipment speed. The components comprising the USDA Flax-PP are the following: a nine-roller crushing calender, top shaker, scutching wheel, and five-roller calender. These modules are set-up independently to allow maximum flexibility for processing samples in any machine, speed, direction, or order for research purposes.

Concurrently, a commercial flax processing facility, Eastern Flax, is located in Kingstree, South Carolina. Both the pilot plant and commercial systems involve the use of the ‘unified line’ plus an additional cleaning system to produce cottonized flax. Fibers separated and removed from flax stalks by other processing methods need to be compared against the standard processing

technique of the Eastern Flax facility or Flax-PP, which both produce uniform and consistent textile grade flax fibers.

The cotton industry regularly evaluates fiber that (1) enhances the performance of cotton, (2) is natural, and (3) increases the demand and profitability of cotton. Recently textile research has dealt with blends of cotton and flax (Nuessli, 1995; Czekalski et al., 2000; Akin et al., 2001). Flax fibers must be separated, by retting, from the pectin substances, which bind the fibers to the shive and other non-fiber components in the stalk. Historically, two types of retting methods have predominated, namely, dew- and water-retting. Because of the disadvantages of these methods, alternatives such as enzyme-retting are currently being developed and evaluated for pilot plant processing.

The quantity of enzyme-retted short staple textile grade cottonized flax fiber is often limited in pilot plant processing. The CST adapted for flax fiber may provide useful data in a short time with limited fiber. The fiber and yarn properties and processing performance obtained from the miniature spinning may help grade the fibers and/or blends relative to their potential spinning capabilities.

Establishing a flax fiber industry in the southern U.S. can enhance associated agricultural sectors, including processing facilities, related maintenance services, and seed production industries. The cotton gin, which cleans cotton to create textile-grade fibers and extracts trash in the process, employs a similar purpose for that in creating flax fiber. A cotton gin is dormant for a large portion of the year and could be used during this period to process retted flax stalks. Flax fiber production in cotton’s off-season permits efficient use of labor, buildings, and equipment. Anthony (2002) has shown that the fiber can be successfully separated from chopped seed flax straw. The most effective way to separate chopped seed flax fibers from the stalks is by using three-cylinder cleaners followed by a saw-type cleaner. Regardless of process technique, processing flax stalks that have been dew-retted with indigenous fungi and bacteria to separate fibers from the stalk creates large quantities of dust. Flax stalks contain approximately 30% fiber and 70% trash that are contaminated with soil and microorganisms throughout dew-retting and harvesting.

Research on cotton dust and byssinosis at the Cotton Quality Research Station (CQRS) has been conducted for over two decades (Chun et al., 2000). The card is the major dust producer in a textile mill (Cocke et al., 1975). Cotton dust research has led to a stringent set of regulations termed the Cotton Dust Standard (Chun, 2001). An experimental completely controlled card room isolated

from processing at CQRS contains a Saco-Lowell card for dust sampling (Cocke et al., 1975).

The long-term inhalation of cotton, flax, or hemp dust results in a shortness of breath, and wheezing due to endotoxins, that are produced in the cell wall of gram-negative bacteria (Chun, 2001). Endotoxins (lipopolysaccharides, LPS) in cotton dust are the most likely etiological agent of byssinosis and essential in studying respiratory dysfunctions (Chun et al., 2000). Cotton dust also initiates process problems. Low efficiency rates during open-end spinning are often caused by various types and sizes of trash particles ( $>500\text{ }\mu\text{m}$ ) including dust ( $<500\text{ }\mu\text{m}$ ) and micro-dust ( $15\text{--}50\text{ }\mu\text{m}$ ) becoming trapped in the rotor that form a ring of debris in the rotor groove (Furter and Schneider, 1993).

The long-term goal is to evaluate cotton/flax blends produced from various processing methods for textile processing. Fibers cleaned from flax stalks by other processing methods must be compared alongside our standard ‘unified line’ processing techniques. As part of this goal, strategies and techniques will be evaluated to optimize the cost effectiveness of flax-ginning, quality of textile grade fiber produced from cotton ginning modifications, blends for textile processing, and the levels of dust generated in processing. Specific objectives addressed in the present work are: (1) to evaluate CST for several cotton/flax blends, (2) to evaluate ginning on flax by two common ginning steps, and (3) to expand miniature spinning to pilot plant blending on a specific flax where dust production in a card room and rotor was studied.

## 2. Materials and methods

### 2.1. Fiber

The different sources of fiber for flax ginning include: (1) ‘Jordan’ flax grown in South Carolina during 2000 and enzyme-retted with 18 mM EDTA and 0.1% Viscozyme, (2) ‘Natasja’ flax grown in South Carolina during 1993 and dew-retted and crimped (Foulk et al., 2001), and (3) ‘Ariane’ flax field-aged and dried from South Carolina in 1999, and enzyme-retted with 50 mM EDTA and 0.05% Viscozyme.

Additionally, an unknown cultivar was grown, harvested, and dew-retted in the Czech Republic and processed through the flax ‘unified line’ manufactured by CML (Humpolec, Czech Republic). These ‘unified line’ cleaned fibers were then processed through Temafa’s Lin Line (Bergisch Gladbach, Germany) resulting in cottonized flax fibers. Properties of ‘unified line’ cleaned fiber used in this study were as follows: upper half mean

length (UHML) of 2.57 cm, micronaire of 4.6, strength of 33 g/tex, and a short fiber content of 32.1% (McAlister et al., 2002). Southeastern upland cotton used in this study was grown, harvested, and ginned by commercial methods. Properties of cotton used in this study had a micronaire of 4.5, UHML of 2.64 cm, uniformity index of 82.1%, short fiber content of 8.2%, strength of 25.3 g/tex, and an elongation of 6.6%.

### 2.2. Flax ginning

The flax ginning was performed in Prattville, AL by Continental Eagle Corporation on their pilot plant equipment. Dew-retted ‘Natasja’, enzyme-retted ‘Jordan’, and enzyme-retted ‘Ariane’ were all processed with this ginning machinery.

The first piece of machinery used in processing flax was the Super 96 Feeder (Continental Eagle, Prattville, AL). The Super 96 Feeder has a constant feeding mechanism for the main extractor cylinder and is designed for cotton trash removal (Fig. 1). The feed rollers ( $0.42\text{ m L} \times 0.15\text{ m o.d.}$ ) were set to rotate at 1 rpm feeding the spiked cylinder ( $0.42\text{ m L} \times 0.33\text{ m o.d.}$ ) that agitates and conveys the stalk material to the saw cylinder. The extractor saw cylinders ( $0.42\text{ m L} \times 0.42\text{ m o.d.}$ ) rotated at 460 rpm with fibers subsequently removed by doffing cylinders ( $0.42\text{ m L} \times 0.30\text{ m o.d.}$ ). All samples were processed through the Super 96 Feeder.

The second piece of pilot plant ginning equipment used in processing flax was the Golden Eagle 24D lint cleaner (Continental Eagle, Prattville, AL), which is a high capacity, effective and efficient cotton lint cleaner. Stalks formed a batt on a condenser ( $0.48\text{ m L} \times 0.61\text{ m o.d.}$ ) and were fed through compression rollers ( $0.48\text{ m L} \times 0.15\text{ m o.d.}$ ). The 24D lint cleaner has a set of feeding rollers ( $0.61\text{ m L} \times 0.11\text{ m o.d.}$ ) that rotate at 183.5 rpm and feed the saw cylinder ( $0.61\text{ m L} \times 0.61\text{ m o.d.}$ ) that turns at 540 rpm with fibers subsequently removed by the doffing cylinder ( $0.61\text{ m L} \times 0.44\text{ m o.d.}$ ) (Fig. 2). Enzyme-retted ‘Jordan’ and ‘Ariane’ were processed through the 24D lint cleaner one time, whereas the dew-retted ‘Natasja’ was processed two times.

### 2.3. Miniature spinning

Miniature spinning began by passing the refined flax fiber through the Shirley Analyzer (Shirley Institute, Manchester, England) one time to isolate the finer flax fibers from the shives, trash, and coarse fibers. The Shirley Analyzer has proven advantageous in separating textile grade flax fibers. The Shirley Analyzer consists of a feed table, feed roll, lickering, baffles, air blast and

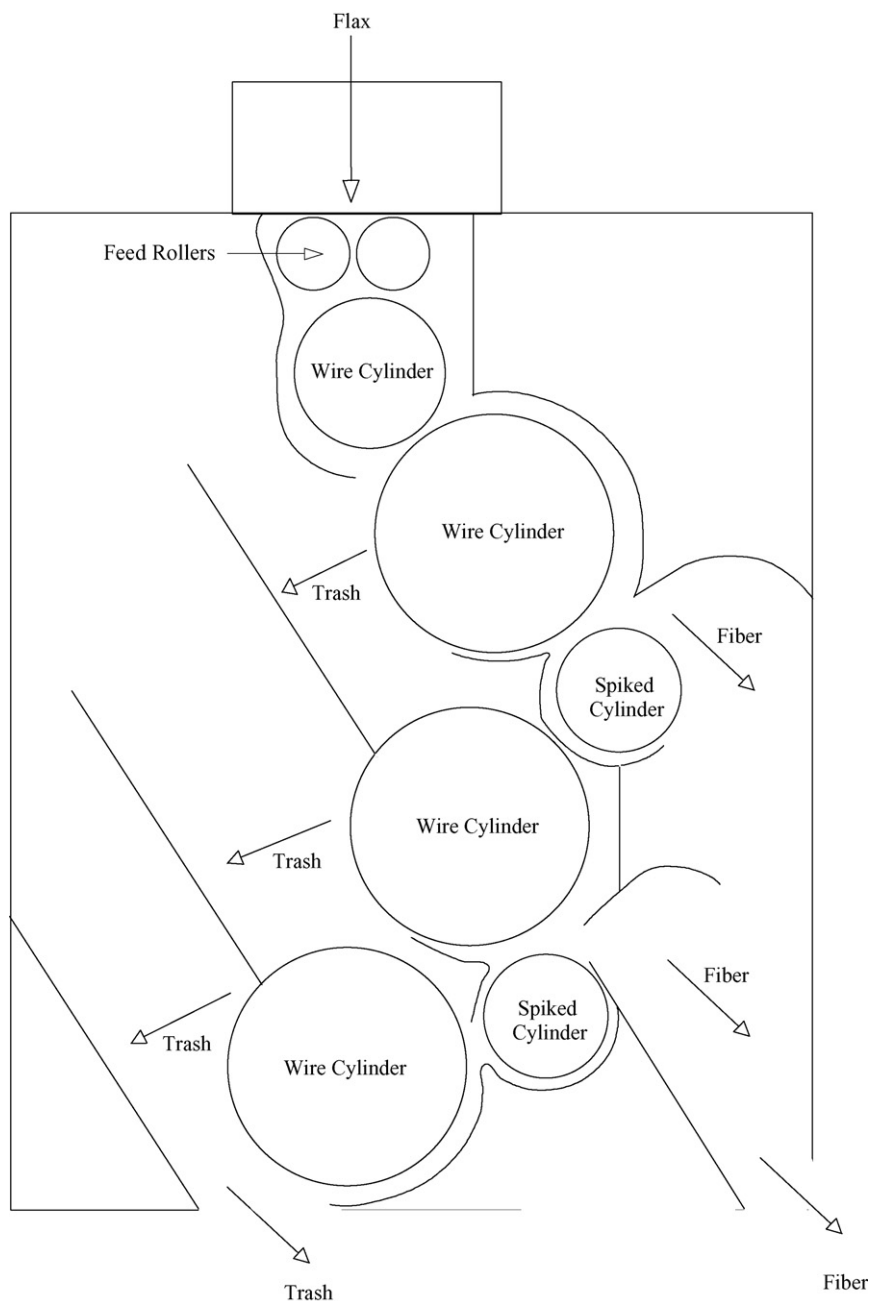


Fig. 1. Gin saw extractor feeder (continental model Super 96 Feeder).

condenser designed for cotton fiber and foreign matter laboratory separation (Pfeiffenberger, 1944).

Cotton fibers were also processed in the Shirley Analyzer to remove cotton trash. Known weights of each of these Shirley analyzed fiber samples were blended in the ratio required for spinning. This sample of two different fiber samples was then intimately combined by hand by mixing small tufts of fiber. This hand-blended sample

was then passed through the Shirley Analyzer for intimate and uniform blending.

These clean and Shirley analyzed samples were placed into a small card feed tray on the back side of a Saco Lowell card (Landstreet et al., 1959, 1962; Ewald, 1975). The sample was carded to provide further opening, blending, cleaning, and production of a web. This web was collected by vacuum on a drum in front of the

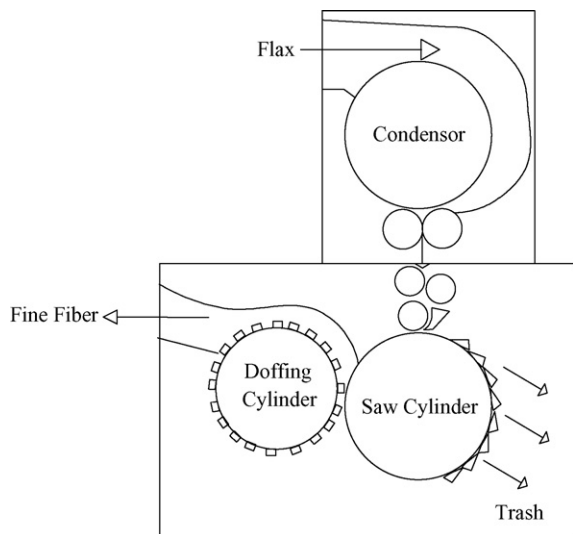


Fig. 2. Unit controlled-batt saw lint cleaner (continental model 24D Golden Eagle lint cleaner).

card. The lap of the produced card web was 1.5 m long and 0.22 m wide. The lap was then processed through drawing to produce a parallel, uniform blend of fibers to deliver a sliver of a specified weight (Landstreet et al., 1959, 1962; Ewald, 1975).

The cotton/flax blend slivers could be spun on an open-end or miniature ring spinning system. Yarns produced in this study were spun on an open-end into a 6/1 Ne yarn using a state-of-the-art Schlafhorst SE-11 (American Truetzschler Inc., Charlotte, NC). The 40-T rotor spun at 71,000 rpm along with a B174 combing roll spinning at 8000 rpm. The twist multiplier was 136.36  $\alpha$ m.

#### 2.4. Pilot spinning laboratory

Flax stalks was processed through the 'unified line' processing equipment, cottonized on Temafa's Lin Line, and spun in various blends to study dust potential. Each cotton/flax blend (100/0, 75/25, 50/50, 25/75, and 20/80) was based on a ratio of starting fiber weights, which was combined and added to a blending hopper. This 23 kg lot of blended fiber was thoroughly mixed before being fed to a modern Truetzschler cleaning line (American Truetzschler Inc., Charlotte, NC). The cleaning line contains an Axi-Flow cleaner, a GBRA blending hopper, a RN cleaner, and a RST cleaner followed by a DUSTEX fine dust remover (McAlister, 2001) before being fed by chute to a Saco Lowell card (Cocke et al., 1975) operating at 27.3 kg/h.

The Saco Lowell card is located in a card room isolated from processing. During carding each blend, dust

was collected in the card room on a high volume area sampler (General Metal Works Inc., Village of Cleves, OH).

One process of drawing, six doublings, was performed on a Rieter RSB draw frame (Rieter Corp., Spartanburg, SC). The open end Schlafhorst SE-11 spinning setup was identical to miniature spinning. The twist multiplier was 136.36  $\alpha$ m for blends less than 50% and 154.55  $\alpha$ m for blends more than 50%. At each end down (yarn end breakage) in spinning and at the conclusion of processing, the buildup of dust in the rotor grooves was collected. Analyses of aromatics, cutins, and waxes in rotor dust were previously described (Morrison and Akin, 2001).

#### 2.5. Yarn testing

Tensile properties of produced yarns from miniature spinning and pilot plant spinning were evaluated for single end yarn strength on the Statimat-M (Lawson-Hemphill, Central Falls, RI) using standard test methods (ASTM International, 1994). Classifying and counting faults in yarn determined using standard test method (ASTM International, 2001) to determine mass coefficient of variation (CV) of yarn width and nep imperfections (200+) per 914 m evenness on the Uster II Evenness Tester (Uster Technologies Inc., Knoxville, TN).

#### 2.6. Endotoxin assay

Total dust from the five-cotton/flax blends (100/0, 75/25, 50/50, 25/75, and 20/80) collected with an EPA type high volume area sampler (Morey and Bethea, 1975) was evaluated for endotoxins. For a comparison type analysis, the five treatments of bulk dust collection with three replications were performed. The dust was collected on a Type A glass fiber filter (Gelman Sciences Inc., Ann Arbor, MI). Using an endotoxin free spatula, 1 g of this dust was removed and transferred to PVC filters. Dust and PVC filters were transferred to dilution blank for assay. Endotoxin assay was performed according to Chun et al. (2000).

### 3. Results and discussion

For the flax miniature spinning, the Shirley Analyzer has proven advantageous in separating coarse and fine fibers and creating an intimate blend for spinning. The Shirley Analyzer isolates the finer flax fiber from the shives, trash, and coarse fibers. Finer fibers can then be combined with cotton by hand mixing smaller fiber



Table 1  
Miniature spinning yarn properties of cotton/flax (50/50) blends<sup>a</sup>

Fiber source	Ginning <sup>b</sup>	Single end strength <sup>c</sup> (g/tex)	Elongation <sup>c</sup> (%)	Mass evenness <sup>d</sup> (CV)	Nep imperfections (914 m) <sup>d</sup>	Ends down (50 g)
Fiber flax <sup>e</sup>	None	8.70 ± 0.25	4.85 ± 0.12	18.74	20	0
Natasja <sup>f</sup>	Super 96 Feeder and 24D lint cleaner (2×)	9.26 ± 0.19	5.24 ± 0.11	17.61	40	0
Jordan <sup>g</sup>	Super 96 Feeder and 24D lint cleaner (1×)	7.85 ± 0.25	5.27 ± 0.15	19.79	40	4
Mature Ariane <sup>h</sup>	Super 96 Feeder and 24D lint cleaner (1×)	6.91 ± 0.26	4.90 ± 0.15	22.97	70	2
Upland cotton 100%	Traditional	10.67 ± 0.20	7.71 ± 0.09	12.36	10	0

<sup>a</sup> Shirley analyzed and hand-blended (50:50 original weight basis) on Shirley Analyzer and carded to form sliver and yarn on traditional cotton equipment. Southeastern upland cotton used in this study was grown, harvested, and ginned by commercial methods. Actual proportion levels likely less than stated blend due to losses during processing. Values are mean ± standard error of mean.

<sup>b</sup> Flax processed through Continental Eagle ginning pilot plant. The machinery used in processing flax consisted of the Super 96 Feeder and Golden Eagle 24D lint cleaner (Continental Eagle, Prattville, AL).

<sup>c</sup> Single end strength and elongation tested on a Statimat-M (Lawson-Hemphill, Central Falls, RI).

<sup>d</sup> Mass coefficient of variation (CV) of yarn width and nep imperfections (200+) per 914 m evenness on the Uster II Evenness Tester (Uster Technologies Inc., Knoxville, TN).

<sup>e</sup> Unknown fiber flax cultivar grown, harvested, and dew-retted in the Czech Republic and processed through the ‘unified line’ of CML (Humpolec, Czech Republic).

<sup>f</sup> Grown as a winter crop in 1993 in coastal plain region of South Carolina, dew-retted and crimped at 80 N (Foulk et al., 2000).

<sup>g</sup> Grown as a winter crop in 2000 in coastal plain region of South Carolina, crimped at 80 N, immersed in retting solution (25 mM EDTA and 0.1% Viscozyme) in water, pH 5.0, for 2 min, incubated at 40 °C for 24 h, washed, dried.

<sup>h</sup> Grown as a winter crop in 1998/1999 in coastal plain region of South Carolina and harvested as a late harvest for fiber and seed. Crimped at 80 N, immersed in retting solution (50 mM EDTA and 0.05% Viscozyme) in water, pH 5.0, for 2 min, incubated at 40 °C for 24 h, washed, dried.

tufts. An intimate and uniform blend is created by a second pass through the Shirley Analyzer. Passing this blend through the back side of a Saco Lowell card provides further opening, blending, cleaning, and produces a uniform mix of fibers. This lap is processed through drawing to produce sliver containing a parallel, uniform blend of fibers and specified weight for further spinning. Miniature-spinning differences are detectable and can be attributed to combination of varietal, harvesting, cleaning, and retting variables (Table 1).

Flax fiber has customarily been divided into two classes, namely long-line fiber and tow. Tow is a byproduct of long-line fiber production and consists of short staple fibers. Flax fibers cottonized from the entire plant are the focus in our overall goal, because short staple spinning units dominate North American textile mills. Different types of flax cleaning systems exist worldwide. In this study, selective pieces of basic and traditional gin equipment were utilized to generate textile grade fiber from various sources of properly retted flax stalks. In the U.S., ginning equipment cleans and extracts trash from cotton. A patent has been issued for an interrelated device based on cotton ginning equipment that separates fiber and contaminants from flax straw (Anthony, 2003). Unmodified cotton gin pilot plant equipment appears able to process adequately small samples of properly

retted flax stalks. Several hundred cotton gins process cotton in the U.S. and these gins are repaired in the off-season and remain dormant for a large portion of the year until the next year’s processing. These gins could be retrofitted for flax ginning. As demonstrated in Table 1, yarns can be produced from small quantities of flax stalks processed through selective pieces of “unmodified” pilot plant ginning equipment with yarn properties comparable to the ‘unified line’ yarns.

In this study, flax ginning produced textile grade fiber and yarn from various sources of properly retted flax stalks. Yarns quality measurements comprised of single end strength and elongation, yarn evenness and imperfections, and yarn appearance (Table 2). Open end 100% cotton yarns (6/1 Ne yarn) acceptable for fabric construction may range from 9 to 12 g/tex with 7–11% elongation; however, these 100% cotton yarns contain no bast fibers which exhibit low fiber to fiber cohesion. A decrease in fiber cohesion between individual fibers decreases the single end strength of blended cotton/flax yarn with blended yarn in this study suitable for further processing. Actual flax proportions likely are less than the initial flax blend level due to losses during processing. These open end spinning results summarize the properties of cotton/flax blends and the starting point for improvements.

Table 2

Pilot plant spinning yarn properties of cotton/flax blends<sup>a</sup>

Flax level <sup>b</sup> (%)	Cotton level <sup>c</sup> (%)	Single end strength <sup>d</sup> (g/tex)	Elongation (%)	Mass evenness <sup>e</sup> (CV)	Nep imperfections <sup>e</sup> (914 m)	Yarn appearance
0	100	15.60 ± 0.05	8.16 ± 0.02	11.6	0	B+
25	75	13.22 ± 0.04	6.47 ± 0.02	15.3	14	C+
50	50	10.53 ± 0.05	5.64 ± 0.02	18.9	29	C
75	25	10.11 ± 0.07	4.76 ± 0.02	22.3	125	D
80	20	7.70 ± 0.14	3.56 ± 0.05	25.4	93	D

<sup>a</sup> Processed through modern Truetzschler cleaning line and fed by chute to a Saco Lowell card in CQRS pilot plant (Clemson, SC) to form sliver and yarn on open end Schlafhorst SE-11. Actual proportion levels likely less than stated blend due to losses during processing. Values are mean ± standard error of mean.

<sup>b</sup> Unknown fiber flax cultivar grown, harvested, and dew-retted in the Czech Republic and processed through the ‘unified line’ of CML (Humpolec, Czech Republic).

<sup>c</sup> Southeastern upland cotton used in this study was grown, harvested, and ginned by commercial methods.

<sup>d</sup> Single end strength and elongation tested on a Statimat-M (Lawson-Hemphill, Central Falls, RI).

<sup>e</sup> Mass coefficient of variation (CV) of yarn width and nep imperfections (200+) per 914 m evenness on the Uster II Evenness Tester (Uster Technologies Inc., Knoxville, TN).

Flax contains fibers and fiber bundles with varying diameters due to non-uniformity in retting and processing. Without equipment modifications, these fiber diameter variations can be difficult for cotton processing equipment to manufacture into yarn. The larger diameter fibers can be brittle, bulky, less flexible, and not as likely to be properly integrated with cotton and into the yarn. In rotor spun yarns, not all fibers are oriented along the yarn’s length and typically demonstrate about 70% lower strength than ring spun yarn (McCreight et al., 1997). Yarn evenness and defects increased while yarn strength and appearance decreased as the percentage of flax increased. Yarns with mass uniformity along its length usually have higher strength (McCreight et al., 1997). Yarn unevenness is often a desirable trait of flax yarns because it translates into a unique look and feel

for the fabric. This flax characteristic is likely attributed to fiber blend non-homogeneity, mixing of convoluted and wavy cotton fibers with straight non-crimped flax fibers, varying fiber bundle diameters, and a high level of short flax fiber. Fiber length and consistency must be preserved to obtain optimal yarn quality.

In this study, more dust was collected using an EPA high volume area sampler with increasing levels of flax fiber (Table 3). It is difficult to ascertain whether the dust collected on the filter is homogeneously distributed and representative of air-borne dust. These bulk samples may indicate biased readings due to a possible sedimentary type dust distribution on the filter. Regardless, increasing flax blend levels concurrently increased the endotoxin level of collected dust (Table 3). These data are an initial probe for future studies to evaluate genera and colony

Table 3

Dust collection results<sup>a</sup>

Flax level <sup>b</sup> (%)	Cotton level <sup>c</sup> (%)	Card room dust		Rotor dust		
		Dust generation (mg/min)	Endotoxin level (EU/mg)	Aromatic (mg/g)	Cutin (mg/g)	Wax (mg/g)
0	100	4.3	529 ± 127	na <sup>d</sup>	na <sup>d</sup>	na <sup>d</sup>
25	75	4.4	1783 ± 183	na <sup>d</sup>	na <sup>d</sup>	na <sup>d</sup>
50	50	11.7	2343 ± 363	6.8 ± 1.2	16.0 ± 2.0	14.7 ± 2.3
75	25	13.0	2243 ± 637	4.8 ± 0.3	8.8 ± 0.7	19.2 ± 1.0
80	20	12.0	2619 ± 274	2.4 ± 0.3	14.6 ± 1.1	18.4 ± 0.4

<sup>a</sup> Processed through modern Truetzschler cleaning line and fed by chute to a Saco Lowell card in CQRS pilot plant (Clemson, SC) to form sliver and yarn on open end Schlafhorst SE-11. Actual proportion levels likely less than stated blend due to losses during processing. Values are mean ± standard error of mean.

<sup>b</sup> Unknown fiber flax cultivar grown, harvested, and dew-retted in the Czech Republic and processed through the ‘unified line’ of CML (Humpolec, Czech Republic).

<sup>c</sup> Southeastern upland cotton used in this study was grown, harvested, and ginned by commercial methods.

<sup>d</sup> Insufficient rotor dust collected for chemical analysis at the completion of open end spinning.

forming units and to provide dust sample outcomes in a cotton/flax comparison type analysis. Compared with the dew-retted fibers, enzyme-retted fibers undergo an enzyme-soaking, enzyme-retting, triplicate water rinse, and drying (Akin et al., 2001). Foulk and Chun (unpublished results, 2001) have demonstrated that dew-retted fibers appear to generate more dust with a cartridge collection in the exhaust of a Shirley Analyzer and during card web production than enzyme-retted fibers.

The lowest flax blend level (25%) and 100% cotton demonstrated inappreciable rotor dust, but over extended time periods rotor dust would likely accumulate. Rotor dust collected during ends-down and at the conclusion of spinning also demonstrated related trends with increasing levels of flax (Table 3). The cutin and wax components predominated over the aromatic compounds comprising the dust, likely arising from the cuticle remaining on the fibers. This study demonstrates that higher levels of flax fiber present additional processing and spinning challenges.

#### 4. Conclusions

The CST was successfully modified by utilizing the Shirley Analyzer for fiber cleaning and blending prior to carding. It appears that this test can be used to produce flax blend yarns from very small flax fiber samples, thus reducing time and cost. Selective pieces of basic and traditional gin equipment can be utilized to generate textile grade fiber from various sources of properly retted flax stalks. Unmodified cotton gin pilot plant equipment appears able to process adequately small samples of properly retted flax stalks. This fiber approached the quality of flax fiber obtained through specialized flax processing equipment and was incorporated into quality flax yarn by modifying the CST. Pilot plant spinning of various cotton/flax blends demonstrates that increasing the amount of flax furthermore generates additional processing dust in an isolated card room and in the rotor during open-end spinning thus degrading yarn quality.

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